BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 06014

SUBJECT: Integrated Manned Space Flight Program Traffic Model Case 105-4

DATE: June 4, 1970

FROM: E. M. Grenning

ABSTRACT

Using the integrated manned space flight program corresponding roughly to the maximum program (Option I) in the Presidents' Space Task Group (STG) report, traffic models for earth orbital operations, lunar exploration activities, and future manned planetary missions are derived and discussed. The data presented here is consistent with vehicle size data and program guidelines that existed during the development of the integrated plan. No effort has been made to maintain currency with evolving vehicle configurations.

The years covered by the earth orbital and lunar exploration traffic models are from 1970 to 1984. The model for manned planetary operations, not referenced to any specific calendar year, covers a seven year duration.

The final steady state traffic for all STG options is about the same. The principle differences between Options I, II, and III of the STG report is the rate of acceleration to steady state. Consequently the traffic models presented here for the steady state period should be applicable to all of the options.

For the program considered the cislunar flight network achieves an operational steady state in 1982 with an annual traffic input of 90 to 95 space shuttle flights and two Int-21 launches. The steady state output of the system consists of the science, applications and technology activities associated with the various stations located throughout cislunar space including the use of the low altitude earth orbit station as a launch control center for unmanned planetary probe injections.

Additional annual traffic to support manned planetary operations does not exceed 24 space shuttle flights and four Int-21 launches. The cislunar and manned planetary input traffic can be directly added to determine the gross traffic support requirements, recognizing that the injection date of the first interplanetary flight must be during the calendar year of the mission opportunity.

(NASA-CR-110624) INTEGRATED MANNED SPACE FLIGHT PROGRAM TRAFFIC MODEL (Bellcomm, Inc.) 19 p

N79-71835

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1.0 Introduction

The mission modes of the integrated plan corresponding roughly to the maximum program in the Space Task Group (STG) report are used to synthesize traffic models for earth orbital and lunar exploration activities. (Reference 1) The model for earth orbital operations includes provision for the injection of unmanned planetary probes from low earth orbit onto their respective transplanetary trajectories. A model for manned planetary operations is also presented but is not referenced to any specific calendar year thus leaving as an open question the time at which this kind of activity would be initiated. The effect of any given launch date for a manned planetary mission on the earth orbital and lunar exploration traffic can then be examined by merely adding the manned planetary traffic.

The years covered by both the earth orbital and lunar exploration traffic models are from 1970 to 1984 which the duration covered by the manned planetary model is seven years. Using a summary description of the integrated plan mission modes as a point of departure the earth orbital, lunar exploration and manned planetary models are derived and discussed in some detail below.

2.0 Mission Modes and Vehicles

The integrated program consists partially of the systematic establishment of semi-permanent manned bases in various locations in cislunar space and eventually in interplanetary space. The parallel introduction of low cost transportation systems provided for the purpose of economically moving cargo and personnel to and from the bases is the other important ingredient of the program. The mission mode corresponding to each program element is depicted schematically in Figure 1, and is summarized with vehicle descriptions below.

2.1 Low Altitude Earth Orbit Space Station

The station is located in earth orbit at an altitude of 200 to 300 nm at a currently unspecified inclination. The vehicle is used as a platform and/or control center for a wide spectrum of science, applications and technology (SA&T) operations. It is also used as a satellite repair facility, out bound cargo depot and orbital assembly and launch operations center for lunar and geosynchronous logistics, and unmanned and manned interplanetary missions.

2.2 Geosynchronous Earth Orbit Space Station

The station operates in a geosynchronous equatorial orbit and is used as a platform and/or control center for a variety of SA&T functions. The vehicle is also used as a satellite repair facility.

2.3 Lunar Orbit Space Station

The station is located in a low altitude high inclination lunar orbit. A spectrum of remote sensing SA&T experiments as well as lunar surface sample analysis are performed on board. The vehicle is also used as a base for early lunar exploration and as a cargo and refueling depot for surface base logistics support.

2.4 Lunar Surface Base

The lunar surface base is located at an appropriate site on the surface and serves as an SA&T facility as well as a point of embarkation for manned and unmanned lunar surface expeditions.

2.5 Planetary Orbit Space Station

The station is the mission module portion of the planetary space vehicle that is placed into a low altitude mars orbit. Similar in design to the earth and lunar orbit stations, it serves as a crew living quarters and center of operations for the out bound, planetary orbit, and return phases of a manned mars mission.

2.6 Planetary Surface Base

It is anticipated that eventually a manned surface base will be established on Mars. Similar to the lunar surface base, it would serve as an SA&T facility as well as a center of operations for manned and unmanned Martian surface expeditions.

2.7 Apollo Applications Dry Work Shop (DWS)

The dry work shop is a precursor to the earth orbit space station and thus will cover a narrower range of SA&T activities concentrating on the effects on man of long duration space flight (i.e. up to 56 days) and solar astronomy.

2.8 Space Shuttle

The shuttle is a low cost launch vehicle which can deliver 50,000 lbs. of cargo and up to 12 people to low altitude earth orbit. The vehicle cargo bay is 15 feet in diameter and 60 feet long. The vehicle is capable of 100 reuses.

2.9 Int-21

The Int-21 is a two stage (SIC&SII) expendable launch vehicle used to deliver payloads to low earth orbit that are too large for the space shuttle to accommodate. The vehicle payload for this mission mode is 250,000 lbs with a maximum diameter of 33 feet.

2.10 Nuclear Shuttle

The crew rotation/lunar logistics mission for the nuclear shuttle is the delivery of 90,000 pounds of cargo and up to 6 people to the lunar orbit space station and the return of 10,000 pounds of cargo and 6 people to the earth orbit station. The unmanned lunar logistics mission consists of 100,000 pounds of cargo delivered to the lunar orbit station and 10,000 pounds returned to the earth orbit station. The nominal geosynchronous crew rotation/logistics mission delivers 90,000 pounds of cargo and up to 6 people to the geosynchronous station and transports 6 people to the earth orbit station on the return flight. The vehicle consumes 240,000 pounds of liquid H_2 propellant on each logistics flight. It is capable of 10 reuses.

2.11 Space Tug/LM-B

The two versions of this fully reusable vehicle are the LM-B, which is used for lunar surface exploration and crew rotation/logistics support of the lunar surface base, and the space tug which is used for in situ earth satellite repair and earth orbital assembly operations. Space tug propulsion modules are used for unmanned planetary probe injections. (Reference 2)

There are two LM-B's assigned to the lunar orbit station, one to perform surface sorties and the other available as a rescue vehicle if the need should arise. A single space tug is assigned to each of the earth orbit stations and the number of space tug propulsion modules needed for planetary probe injections varies from 2 to 4 depending on the year. The assumed vehicle design life is one year and its propellant capacity is 40,000 pounds of liquid O_2 and H_2.

2.12 Planetary Space Vehicle

To maximize crew safety a dual planetary mission mode is adopted which consists of two identical planetary space vehicles performing the transfer to Mars and back to Earth in convoy fashion. The propulsion for each vehicle consists of three nuclear shuttles two of which perform the injection and return to earth orbit for use in cislunar operations while the third continues on to Mars with mission and payload modules attached. After achieving Mars orbit and after sufficient site survey through remote sensing and unmanned probe investigation, surface exploration is initiated. At the conclusion of exploration activities the nuclear shuttle brings the mission module back to earth and into an elliptical recovery orbit. The mission is concluded by using another nuclear shuttle to transport the returned planetary space vehicle to the vicinity of the low altitude earth orbit station. The only system elements not recovered are the payload module and transportation system used between Mars orbit and the surface.

2.13 Mars Excursion Module

Transportation between the planetary space vehicle in Mars orbit and the surface is provided by an expendable two stage vehicle; the mars excursion module. The descent mode consists of aerodynamic followed by propulsive deceleration while ascent is performed by the separate propulsive stage delivered to the surface by the descent stage.

2.14 Saturn IB

The two stage Saturn IB (S-IB&S-IVB) is used as a crew rotation/logistics vehicle for the Apollo Applications DWS; the precursor of the low altitude earth orbital space station.

2.15 Saturn VB/Apollo

The Saturn VB/Apollo is the expendable system used for lunar exploration prior to the availability of the lunar orbit station and reusable LM-B vehicle. Basically, it is an upgraded Apollo system allowing lunar surface stay times of up to 3 days with a discretionary payload of 1000 pounds, and an increased CSM mission duration of 16 days.

2.16 Saturn VC

The four stage Saturn VC (Sat V plus space tug propulsion module) is the expendable lunar logistics vehicle used prior to the availability of the reusable nuclear shuttle. Its payload capability to the lunar orbit station is about 100,000 pounds. This assumes that the Sat V vehicle has performance equivalent to 120,000 pounds TLI.

3.0 Earth Orbital Operations

The earth orbit traffic model is given in Figure 2 and the unmanned planetary probe launches programmed for the years 1976 through 1984 (allowance for which is included in the model) as presented in Reference 2, are listed in Table 1. The model is arranged with a general missions schedule appearing at the top of Figure 2 followed by a launch schedule for each of the three launch vehicles used for earth orbital missions. To provide increased visibility the launch schedule for each vehicle is further broken down according to the objective and/or payload for the mission.

Earth orbital activities are generally composed of three types of operations: low earth orbital; geosynchronous earth orbital and unmanned planetary probe injection from low earth orbit.

3.1 Low Earth Orbit

Low earth orbital activities begin in 1972 with the first AAP dry workshop launched on an Int-21, and logistics support being provided by Saturn IB launches. In early 1975 the newly developed space station module takes the place of the dry workshop in low earth orbit via Int-21 launch. Logistics support is provided by another newly developed system, the space shuttle. In 1979, 1980 and 1981 additional space station modules are placed in low earth orbit with Int-21's for the purpose of expanding the space station into a considerably larger space base.

3.1.1 Space Tug Operations

Starting in 1976 there will always be one space tug assigned to the space station and later to the space base. The space tug vehicle is too large to be transported in the shuttle cargo bay and therefore must be placed in orbit by an Int-21. The assumed space tug life time of one year establishes the need for one Int-21 launch per year. The space tugs (LM/B's) needed for operations in other areas of the program make up the remainder of the Int-21 payload. In the years 1979, 1980 and 1981 an additional Int-21 launch is needed for delivery of space tugs to low earth orbit. This will be discussed in more detail.

FIGURE 2 - EARTH ORBIT TRAFFIC MODEL

CALENDAR YEAR	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
EARTH ORBIT MISSIONS															
AAP WORKSHOP (DWS)			Δ		Δ										
MANNED LOGISTICS			ΔΔ	Δ	ΔΔ Δ	Δ Δ	Δ								
SPACE STATION IN ORBIT						Δ	∿6/YR		∿10/YR	∿30/YR			∿90/YR		
MANNED SHUTTLE LOGISTICS						ΔΔ Δ	<—	—>	<—	—><—	—><—	—	—	—	—>
UNMANNED LOGISTICS							Δ	Δ Δ	Δ Δ	ΔΔ	ΔΔ	ΔΔ	ΔΔ	ΔΔ	ΔΔ
GEOSYNCHRONOUS STATION											Δ				
MANNED NUCLEAR SHUTTLE											Δ	4	4	4	4
SPACE BASE BUILDUP										Δ	Δ	Δ			
SAT-IB															
AAP DWS															
CREW ROTATE + LOG.			ΔΔ	Δ	ΔΔ Δ	Δ Δ	Δ								
INT-21															
LEO (AAP DWS)			Δ		Δ										
LEO (SSM)						Δ				Δ	Δ	Δ			
GSEO (SSM)											Δ				
NUCLEAR SHUTTLE								Δ		Δ		Δ	Δ	Δ	Δ
E.O. & U/M PLANETARY INJ.							Δ	Δ	Δ	ΔΔ	ΔΔ	ΔΔ	Δ	Δ	Δ
SPACE TUGS*							(3)	(5)	(3)	(2)(3)	(2)(4)	(2)(4)	(4)	(4)	(4)
SPACE SHUTTLE															
POLAR SORTIES								2	2	2	2	2	2	2	2
SPACE STATION/BASE						3	6	8	8	10	10	10	10	10	10
CREW ROTATE + LOG.															
GSSS, CREW ROTATE +															
LOGISTICS												7	7	7	7
GSSS, PROPELLANT											6	18	18	18	18
NUCLEAR SHUTTLE															
INITIAL PROPELLANT								1		1	0	1	1	1	1
U/M PLANETARY SPACE TUG															
PROPELLANT							2	4	4	2	2	4	0	4	2

*NUMBER IN BRACKETS INDICATES NUMBER OF SPACE TUGS LAUNCHED ON INT-21 FOR LEO-SSM, GEOSYNCH-SSM AND U/M PLANETARY INJECTION. LUNAR LM/B'S LAUNCHED ON SAME INT-21 ARE INDICATED IN LUNAR EXPLORATION TRAFFIC MODEL.

TABLE 1 - BALANCED BASE PLANETARY PROBE PROGRAM

(POST 1976)

TITLE	LAUNCH YEAR	PROBE WEIGHT	ΔV ABOVE 100NMI CIRCULAR
VENUS EXPLORER ORBITER	1976	650	12900
COMET D'AREST FLYBY	1976	1200	12900
MARS EXPLORER ORBITER	1977	650	12900
MARS HIGH DATA ORBITER	1977	7000	12800
JUPITER-SATURN-PLUTO MARINER-CLASS FLYBY	1977 (2)	1500	25400
MERCURY-VENUS MARINER FLYBY	1978	800	14800
VENUS-MARINER ORBITER	1978	5600	12400
SOLAR ELECTRIC ASTEROID BELT SURVEY	1978	1500	12900
MARS SOFT LANDER/ROVER	1979	6000	12200
JUPITER-SATURN-PLUTO MARINER-CLASS FLYBY	1979 (2)	1500	25400
VENUS EXPLORER ORBITER	1980	650	12900
JUPITER FLYBY/PROBES	1980 (2)	2400	22900
MARS EXPLORER ORBITER	1981	650	12900
SATURN MARINER-CLASS ORBITER/PROBES	1981 (2)	3100	22900
ASTEROID EROS MARINER FLYBY	1981	1000	11800
MERCURY SOLAR ELECTRIC ORBITER	1982	8000	14000
VENUS EXPLORER ORBITER	1983	650	12900
VENUS MARINER ORBITER/ROUGH LANDER	1983	6000	12900
COMET KOPFF MARINER RENDEZVOUS	1983	8500	13400
MARS HIGH DATA ORBITER	1984	7000	12200
MARS SOFT LANDER ROVER	1984	6000	12200

3.1.2 Station Logistics

To support the low earth orbit space station, the space shuttle launch rate starts at 3/Yr in 1975 and increases to a steady state value of 10/Yr in 1979. From 1975 through 1978 three flights per year are devoted exclusively to cargo for the space station with any additional flights devoted to space tug propellants. Because of the beginning of the space base buildup in 1979 the shuttle launch rate for all cargo payloads increases from 3/Yr to 4/Yr resulting in 6 flights per year being devoted to space tug propellants. Since one shuttle payload is about equivalent to one space tug propellant capacity, six full capability sorties can be performed each year for satellite repair, space base construction, etc.

Starting in 1977 2 polar sortie missions per year are assigned to the space shuttle itself. This is needed because the space tug can't reach polar orbit from the nominal space station orbit. A steady state total of 12 space shuttle flights per year are provided for support of low earth orbit operations.

3.2 Geosynchronous Earth Orbit

Geosynchronous earth orbital activities are initiated in 1980 by first placing a space station module (Int-21 launch) in low earth orbit in preparation for its transfer to geosynchronous orbit by the nuclear shuttle. The space station module, a space tug with propellant slightly off loaded and a crew of six comprises the payload that the nuclear shuttle places in geosynchronous orbit. The space tug assigned to the geosynchronous station is transferred to low earth orbit as part of the payload of an earlier Int-21 launch while the crew is transported to orbit aboard the space shuttle.

3.2.1 Station Logistics

After geosynchronous operations commence in 1980, four manned nuclear shuttle logistics flights per year are required for space tug replacement and refueling, crew rotation and general logistics. This, plus the 6 per year needed to support the lunar program call for 10 nuclear shuttle flights per year in all. Since it is assumed that the useful life of the nuclear shuttle is 10 missions a requirement for one new nuclear shuttle per year is established. To remain within the Int-21 payload constraint the nuclear shuttle is delivered to low earth orbit with hydrogen off loaded. A single space shuttle tanker flight then fills the nuclear shuttle tank to capacity. This provides a new fully fueled nuclear shuttle in low earth orbit ready to take aboard cargo and crew for its maiden logistics mission to the geosynchronous station. After the maiden voyage 6 space shuttle tanker flights are required for each nuclear shuttle flight; 5 to fill the hydrogen tank and 1 to fuel the space tug which is needed for assembly operations. This establishes the need for 18 additional space shuttle tanker flights per year. Transportation of geosynchronous cargo, space tug propellant and crew to low earth orbit requires 2 space shuttle flights per nuclear shuttle mission. This establishes a requirement for 8 space shuttle flights per year for geosynchronous logistics which is reduced to 7 because part of the cargo requirement is the new fully fueled space tug brought to low earth orbit as part of the payload of an Int-21 launch. A steady state total of 26 space shuttle flights per year are provided for support of the geosynchronous space station.

3.3 Planetary Probe Injection

The space tug is programmed to be operational in 1976 thus permitting the initiation of unmanned planetary probe injection activities in low earth orbit. The standard injection configuration is a stack of two space tug propulsion modules (PM) used in a fully recoverable mode. To achieve the high energies needed for outer planet missions it is necessary to burn the second PM to completion thus precluding recovery of the second injection stage. Furthermore, to obtain acceptable mission success probabilities for outer planet missions the launch of two identical probes is required thus necessitating the loss of two PM's for each mission of this kind. Therefore, years with no outer planet missions require only 2 PM's while years with one outer planet mission require 4 vehicles.

3.3.1 Space Tug/LM-B Requirements

In parallel with the planetary injection requirement is one space tug per year for the low earth orbit station starting in 1976; one per year for the geosynchronous station starting in 1980 and 2 LM-B's per year for lunar operations starting in 1979. The number of space tugs (LM-B's) that must be delivered to low earth orbit in a given year is obtained by simply adding the above requirements. The result is that the Int-21 payload limitation of 5 fully fueled LM-B's is substantially exceeded in the years 1979, 1980, and 1981 primarily because of the beginning of geosynchronous operations in 1980 and the outer planet mission in each of those years.

For this reason an additional Int-21 launch devoted exclusively to delivery of space tugs to earth orbit is specified in those years. After 1981 the schedule returns to one Int-21 launch per year but with a payload of 6 space tugs using appropriate propellant off loading, and assuming no stack height problems.

3.3.2 Probe Injection Propellants

Only one planetary injection mission can be performed by the fully fueled injection space tugs delivered to earth orbit by the Int-21. The injection vehicles must be refueled by the space shuttle at a rate of 2 flights per probe injection. This results in no more than 4 space shuttle tanking flights in any one year for this purpose.

4.0 Lunar Exploration Operations

The lunar exploration traffic model given in Figure 3 is presented in the same format as the model for earth orbital traffic shown in Figure 2. Lunar exploration activities from 1970 to 1984 can be conveniently separated into two categories; Apollo and post Apollo operations, the former continuing through early 1975 and the latter initiated in early 1976.

4.1 Apollo

Lunar exploration activities using existing Apollo hardware continues at a rate of three missions per year through 1970. Starting in 1971, XCSM's and XLM's (X for extended) will be launched on Sat V B's to perform lunar exploration missions with 3 day lunar surface stay times and up to 16 days of total mission duration at a rate of 2 missions per year through 1974. These extended Apollo operations are terminated with a final mission in early 1975. Through early 1975 the lunar population including both surface and orbital operations never exceeds three astronauts.

4.2 Post Apollo

In the post Apollo era the mode of transporting cargo and crew from low earth orbit to the moon is via the nuclear shuttle. Since the shuttle is not programmed to be operational until early 1979 an interim transportation system, the four stage Sat VC launch vehicle, is used for lunar logistics.

FIGURE 3 - LUNAR EXPLORATION TRAFFIC MODEL

CALENDAR YEAR	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
LUNAR EXPLORATION															
Apollo	▲▲▲														
Extended Apollo		▲ ▲	▲ ▲	▲ ▲	▲▲	▲									
SVC & LM/B Test						△									
Unmanned Logistics							△ △	△	△						
Manned Logistics							▲ ▲	▲	▲ ▲						
Space Station in Orbit							△								
Lunar Surface Base										△					
Manned Nuclear Shuttle										▲	4	4	4	4	4
Unmanned Nuclear Shuttle										△ △	2	2	2	2	2
14 Day Surface Sorties							4	5	4	4	8	8	8	8	8
Lunar Population	3	3	3	3	3	3	4	4	4	4 → 6	12	12	12	12	12
SAT-VB															
XCSM/XLM		▲ ▲	▲ ▲	▲ ▲	▲▲	▲									
INT-21															
LSB (SSM)										△					
Lunar LM/B's*										△ (2)	△ (2)	△ (2)	△ (2)	△ (2)	△ (2)
SPACE SHUTTLE															
Lunar Crew Rotation & Logistics										2	5	5	5	5	5
Lunar Exploration LM/B Propellant										2	6	6	6	6	6
Nuclear Shuttle Propellant										12	36	36	36	36	36
Nuclear Shuttle Disposal Propellant											6	6	6	6	6
SAT-VC															
Lunar Test (SVC & LM/B)						△									
LOSS (SSM & LM/B)							△								
Lunar Log./Crew Rotation (QCSM)							▲ ▲	▲ ▲	▲						
Lunar Logistics (LM/B's & Cargo)							△ △	△	△						

*Lunar LM/B's are launched with Earth Orbital and U/M Planetary Injection LM/B's on Int-21's

Post Apollo activities are initiated in late 1975 with an unmanned lunar flight test mission of the Sat VC launch vehicle and LM/B vehicle. Assuming the test mission qualifies both vehicles for flight operations the lunar orbital space station, a partially fueled LM/B propulsion module and a LM/B crew capsule are placed in a low altitude lunar polar orbit in early 1976.

4.2.1 <u>Interim Station Logistics</u>

Two months later the station is manned by a crew of four transported to the station in a QCSM on the first lunar crew rotation/logistics mission. This flight also carries a fully fueled LM/B and cargo for lunar surface exploration. Two LM/B's one for backup and rescue, and the other for surface sorties, are mandatory to start lunar surface exploration. This ground rule was imposed because of the possible need to rescue marooned personnel from the surface. The partially fueled LM/B delivered with the space station remains at the station as a rescue vehicle while the fully fueled vehicle performs the first lunar surface sortie mission in the second quarter of 1976. The unmanned logistics mission in the third quarter of 1976, provides two full LM/B propellant loads and cargo for surface exploration. The propellant is packaged in stripped down LM/B vehicles (i.e. engines, intelligence and landing systems removed to create a LM/B Tanker) the weight reduction permitting the inclusion of surface cargo while remaining within the Sat VC lunar orbit payload constraint of 100,000 pounds. Two sorties are performed in the third quarter of 1976. The manned crew rotation/logistics mission in the fourth quarter of 1976 brings a fresh crew in a QCSM to the station for the first crew rotation, a full LM/B tanker and cargo for the final surface sortie of 1976, resulting in a total of 4 sorties for the year. In the first year of post Apollo operations a continuous lunar population of 4 is established as opposed to an intermittent population of 3 during Apollo activities.

The lunar logistic mission rate changes from one per quarter in 1976 to one every four months in 1977 starting in January with an unmanned mission for replacement of the initial LM/B PM's which have reached their assumed useful lifetime of about one year. Unmanned logistics missions delivering LM/B tankers and cargo or new LM/B PM's are continued on 8 month centers through March of 1978. Manned crew rotation/logistics missions start in April of 1977, and are performed on eight month centers through August of 1978. The delivered payload consists of the QCSM, a LM/B tanker, lunar surface cargo, and on every other flight starting with the first, LM/B crew capsule replacements. This mode of crew rotation and logistics provides for 5 and 4 lunar surface sorties in 1977 and 1978, respectively. The continuous lunar population level of 4 is maintained.

4.2.2 Station Logistics

The nuclear shuttle becomes operational in early 1979 and in conjunction with the space shuttle assumes the lunar crew rotation and logistics burden. The first nuclear shuttle lunar logistics mission is an unmanned flight which transports two LM/B PM replacements to the moon and returns to earth orbit with two empty LM/B tankers. The tankers are obtained by stripping down the two LM/B's (at the lunar orbital station) that are being replaced. This kind of unmanned nuclear shuttle logistics mission is the first to be performed each year and results in the supply of two new LM/B PM's and the creation of two new tanker modules on a rotating annual basis. The new LM/B PM's are transported to earth orbit as part of the payload of an Int-21 launch. Thus, the history of a lunar operations LM/B PM is; transportation to low earth orbit aboard an Int-21; transportation to the lunar orbital base aboard the nuclear shuttle; lunar surface exploration operations for one year; strip down and use as a lunar logistics propellant tanker for one year; and expend by injecting the tanker into solar orbit aboard a nuclear shuttle which has reached its useful life of one year.

Replacement crew capsules for lunar exploration operations are carried to earth orbit aboard the space shuttle and transported to the moon by the nuclear shuttle. This is done annually, on the second logistics flight of the year.

In general, propellant for two LM/B refuelings are carried on each unmanned nuclear shuttle mission and one refueling on each manned flight. All additional shuttle payload capability is available for lunar exploration and/or discretionary cargo. In the first year of nuclear shuttle operations three lunar logistics missions are performed; two unmanned and one manned. Normally, this would provide propellant for 5 lunar surface sorties in 1979. Since the six man version of the new capsule is used to transport personnel on the nuclear shuttle the single manned logistics flight in 1979 permits the lunar orbit station crew of 4 to be replaced by a fresh crew of 6. A total of 12 tanker and 2 cargo space shuttle flights are needed for logistic support of the three nuclear shuttle missions in 1979.

A steady state level of 4 manned and 2 unmanned lunar logistics/crew rotation missions commence in 1980. This provides cargo and propellant for 8 surface sorties per year and an expansion of the continuous lunar population from 6 to 12 some of which will reside in the lunar surface base. The given rate of 6 space shuttle tanker flights per nuclear shuttle mission establishes a requirement for 36 space shuttle flights per year for nuclear shuttle refueling and payload assembly. Each LM/B tanker capacity requires a single space shuttle flight yielding a total annual requirement of 6 flights while lunar cargo needs are satisfied by 5 space shuttle flights per year.

5.0 Manned Planetary Operations

A feasible manned planetary traffic model is given in Figure 4 presented in the same kind of format as the models for earth orbital and lunar exploration activities. The model is based on an increasing manned Martian exploration capability using only conjunction class missions. Missions and vehicle data are taken from reference 3. Because of future funding uncertainties the model is not specified according to calendar year but is presented as a function of years from the beginning of operations.

There are three overlapping missions indicated, each successive mission employing more ambitious exploration activities. Assuming the initial unmanned probes on the first mission find no significant biological hazard, manned landings will be performed on each of the three flights. These landing operations should culminate in the establishment of a manned Mars surface base on the third mission. Subsequent flights to Mars would be for base expansion, resupply and crew rotation. To avoid an inordinately large number of space shuttle and Int-21 flights in any one year, an effort has been made to spread the assembly and funding of each planetary space vehicle over a period of several years prior to its injection.

5.1 First Mars Mission

On-orbit assembly operations of the two planetary spacecraft for the first Mars mission begin approximately 1.5 years before trans Mars injection. The four nuclear shuttles to be used for trans Mars injection are transported to orbit aboard Int-21 launch vehicles. One space shuttle flight per nuclear shuttle is needed to replace the off loaded hydrogen resulting in a total of 4 space shuttle tanker flights for the year.

The following year the two nuclear shuttles programmed to make the round trip to Mars and back are launched into earth orbit aboard Int-21's. Shuttle propellant is

FIGURE 4 - MANNED PLANETARY TRAFFIC MODEL

	1	2	3	4	5	6	7
1st Mission							
2nd Mission							
3rd Mission							
INT-21 INJECTION NUCLEAR PLANETARY NUCLEAR & MEM PAYLOAD	Δ Δ ΔΔ	Δ Δ ΔΔ	Δ	Δ Δ Δ		ΔΔ Δ Δ	
SPACE SHUTTLE DIRECT LH_2	12	10	19	19	14	28	
OR FUEL DEPOT	20	20	20	20	20	20	20
CREW & LOGISTICS		1		1			1
ORBITAL ASSEMBLY SPACE TUG PROPELLANT		6		6		4	2

off loaded to allow inclusion of a Mars excursion module in both of the Int-21 payloads. Three space shuttle flights per nuclear shuttle are needed to fill its hydrogen tank to capacity establishing a requirement for 6 space shuttle tanker flights in that year. The remainder of the two planetary vehicles including crew living quarters, retrieval facility, expendables module and unmanned sample return probes are placed in earth orbit by two Int-21 launches.

Since orbital assembly operations in constructing the two planetary vehicles are anticipated to be quite extensive a generous allowance of 6 space shuttle flights for space tug refueling has been provided. One space shuttle flight has been allocated for transportation of the crew and their equipment to the assembled planetary space vehicle yielding a total of 13 space shuttle flights required for the second year of manned planetary operations.

5.2 Second Mars Mission

After the injection nuclear shuttles perform their function (See Section 2.11 for planetary mission mode description) they return to earth orbit and, if desired, can be used for cislunar logistics operations until they are needed again for the second Mars mission. Their reuse on the second planetary injection assumes they have been used for no more than 2 or 3 cislunar logistics missions.

In the third year two of the injection shuttles are refueled each requiring 5 space shuttle flights for a total of 10 flights for this purpose. Since the two nuclear shuttles have not yet returned from the first mission the first of two new shuttles for the second mission is launched on an Int-21 in this year. As before hydrogen is off loaded to permit a mars excursion module to be included in the payload. Three space shuttle tanker flights are needed to replace the off loaded hydrogen establishing a total requirement of 13 space shuttle flights for the third year of manned planetary operations.

In the fourth year preparations for the second Mars mission continue. The remaining 2 injection nuclear shuttles are refueled requiring 10 space shuttle tanker flights. The second off loaded nuclear shuttle and mars excursion module are launched into orbit on an Int-21. This establishes a need for 3 space shuttle tanker flights to replenish the off loaded hydrogen. Two Int-21 launches each place living quarters, an expendables module and another mars excursion module in earth orbit. As before 6 space shuttle tanker flights are allocated for space tug refueling and one for personnel and crew equipment transportation. Therefore, the total number of space shuttle flights in the fourth year of operations in 20.

5.3 Third Mars Mission

Toward the end of the fifth year the planetary vehicles from the first dual Mars mission, consisting of two nuclear shuttles each with crew living quarters attached, returns to earth. These nuclear shuttles are used again for another round trip on the third Mars mission.

During the fifth year it is assumed that one of the two returned shuttles is refueled in preparation for the third Mars mission establishing a need for 5 space shuttle tanker flights. One of the injection shuttles is also refueled resulting in a total of 10 tanker flights for the year.

Preparations for the third Mars mission continue in the sixth year. The three remaining injection shuttles and the single remaining planetary shuttle are refueled resulting in a total of 20 space shuttle tanker flights. Two Int-21's are launched, each containing a Mars excursion module and either a Mars surface base of a Mars surface base support system. A second pair of Int-21's are launched the payload of each consisting of a Mars excursion module, and an expendables module. The orbital assembly space tug requirement for refueling is assumed to be 4 space shuttle flights for the year.

In the next and final year two additional space tug refueling shuttle flights and one crew/crew equipment flight are allocated for final preparations prior to injection for the third Mars mission. It is anticipated that after the third mission (assuming a Mars surface base is established) Mars logistics/crew rotation missions of the conjunction class will be performed on approximately two year centers.

5.4 Fuel Depot Considerations

In the present traffic model propellant for each of the three missions is delivered to one or more of the nuclear shuttles as much as 1.5 years prior to the time at which trans Mars injection is executed. Therefore, the nuclear shuttles are, in effect, propellant storage facilities as well as planetary mission propulsion modules. Essentially, this mode achieves the advantage of a separate fuel depot without actually constructing one, ie, the required space shuttle tanker flights are spread over a reasonable period of time. However, it has the disadvantage of making planetary spacecraft assembly operations more expensive propulsively, in that, the nuclear shuttles are considerably heavier when they are fully loaded with propellant than when empty. Ideally, the planetary vehicle should be completely assembled first and then the nuclear shuttle tanks filled with propellant shortly before injection. This can only be accomplished without sacrificing a reasonable time distribution for the required space shuttle tanker flights, if a separate orbital fuel depot is available.

The capacity of a depot conservatively sized to store enough liquid hydrogen for a Mars mission would be about 1.5 million pounds requiring 30 space shuttle tanker flights to fill it. Since there is about 2 years separating each of the Mars injections and since each of the missions approximately depletes the fuel depot a requirement for about 15 space shuttle tanker flights per year is established. The Int-21 launches needed to transport a fuel depot to orbit are not covered in the traffic model.

6.0 Conclusions

Table 2 summarizes by calendar year from 1975 through 1984 the space shuttle and Sat V traffic departing from the earth's surface in support of cislunar operations. Basically, this represents the cargo and propellant input to the emerging integrated manned space flight network which reaches an operational steady state in 1982. The annual steady state traffic consists of between 90 and 95 space shuttle flights and 2 Int-21 launches. The steady state output of the network consists of the SA&T activities associated with the various stations located throughout cislunar space including the use of the earth orbit station as a launch control center for unmanned planetary probe injections.

Incremental earth surface departure traffic to support manned planetary operations is summarized in Table 3. Without an orbital fuel depot, and excluding the first year of operations the number of annual space shuttle flights varies from a minimum of 10 to a maximum of 24. With a fuel depot the number of annual shuttle flights alternates between a minimum of 15 and a maximum of 22. The number of annual Int-21 launches never exceeds four. An overall traffic summary can be obtained by directly adding the summaries in Tables 2 and 3 recognizing that the first planetary injection must coincide with a conjunction class mission opportunity.

E. M. Grenning

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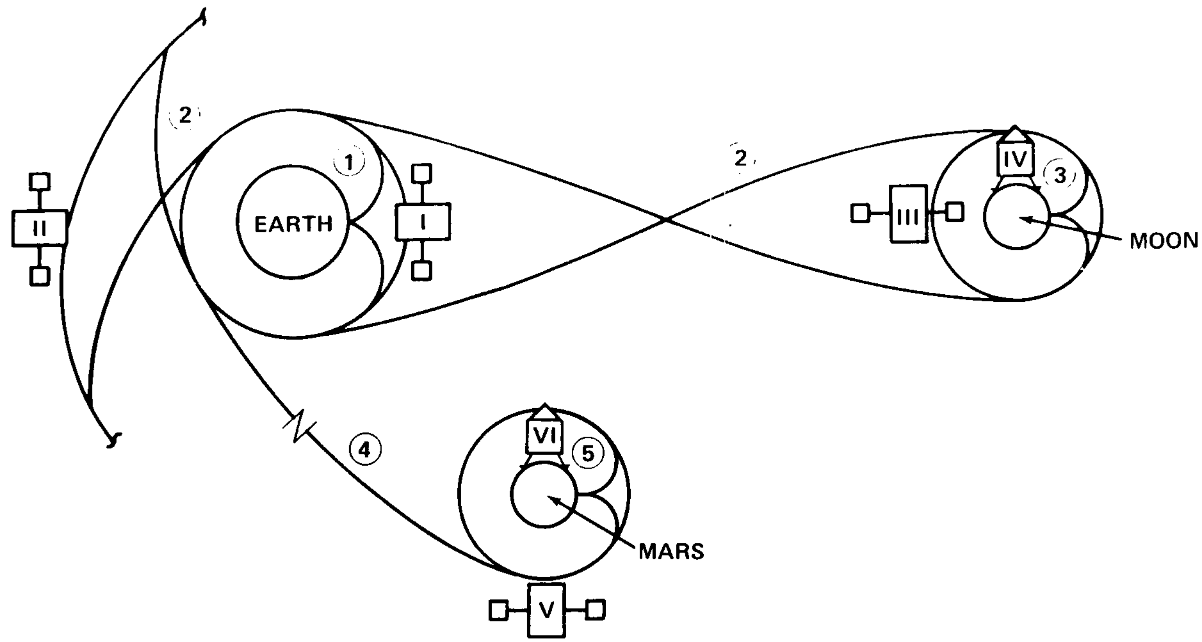
Table 2 - Cislunar Input Traffic Summary

Logistics System		Calendar Year									
		75	76	77	78	79	80	81	82	83	84
Space Shuttle	Earth orbit	3	8	15	14	15	20	42	38	42	40
	Lunar Exploration					16	53	53	53	53	53
Total Space Shuttle Flights		3	8	15	14	31	73	95	91	95	93
Saturn V	Sat VC	2	4	3	2						
	Int-21	1	1	2	2	4	4	5	2	2	2
Total Saturn V Flights		3	5	5	4	4	4	5	2	2	2

Table 3 - Manned Planetary Input Traffic Summary

Logistics System		First Planetary Injection			Calendar Years			
		1	2	3	4	5	6	7
Space Shuttle	No Fuel Depot	4	13	13	20	10	24	13
	Fuel Depot*	15	22	15	22	15	13	18
Int-21		4	4	1	3	0	4	0

*Orbital fuel depot with 1.5 million pound capacity of liquid H_2 is assumed. Int-21 launches needed to place depot in orbit are not included in traffic model.



BASES

EARTH ORBIT

- I LOW ALTITUDE STATION
- II SYNCHRONOUS STATION

LUNAR

- III ORBIT STATION
- IV SURFACE BASE

PLANETARY

- V ORBIT STATION
- VI SURFACE BASE

INTERIM BASE

- I APOLLO APPLICATIONS DWS
- III CSM
- IV LM

TRANSPORTATION

- 1 SPACE SHUTTLE & INT - 21
- 2 NUCLEAR SHUTTLE
- 3 LM-B/SPACE TUG
- 4 PLANETARY SPACE VEHICLE
- 5 MARS EXCURSION MODULE

INTERIM TRANSPORTATION

- 1 SATURN IB/CSM
- 1 & 2 SATURN VB
- 1 & 2 SATURN VC

FIGURE 1 - INTEGRATED PROGRAM MISSION MODES

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1. "An Integrated Program of Space Utilization and Exploration for the Decade 1970 to 1980," NASA, Washington, D.C., July 16, 1969.

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3. H. S. London, et al, "Integrated Space Program: Manned Planetary Missions for the 1980's," Bellcomm Briefing Package, July 1969.

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